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GEOLOGY.—*An outline of the results of a geological reconnaissance of the Republic of Haiti.* WENDELL P. WOODRING.[1]

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INTRODUCTION

According to arrangements between the Department of Public Works of the Republic of Haiti and the United States Geological Survey, a geological reconnaissance of the Republic of Haiti was made in the winter of 1920–1921 under the supervision of the United States Geological Survey. Mr. J. S. Brown, Mr. W. S. Burbank, and I arrived in Port-au-Prince on October 1, 1920. We were in the field continuously until April 15, 1921, when we sailed from Port-au-Prince. We made a general reconnaissance of the entire Republic, including Gonave Island and Tortue Island. A detailed reconnaissance was made of some regions in order to obtain information on certain mineral deposits and on underground water resources. The highest and most inaccessible parts of some of the rugged mountains, such as the Montagnes Noires, the Montagnes de la Selle, and the Montagnes

[1] Published by permission of the Acting Director of the United States Geological Survey and the Engineer-in-Chief of the Republic of Haiti.

de la Hotte, were not examined. The field work and most of the office work was done under the supervision of Dr. T. W. Vaughan of the United States Geological Survey.

A complete report embodying the results of the reconnaissance, illustrated with many maps, diagrams, and photographs, has been prepared for publication, and it is intended to issue a French and an English edition. As this report will not be ready for distribution before the autumn of 1923, the following summary of the results of the reconnaissance is now published.

GEOGRAPHY

All the inhabitants of the Republic know that it is very mountainous. The only extensive plains are the North Plain, the Central Plain, the Artibonite Plain, and the Cul-de-Sac Plain. The Central Plain is the only large interior plain. The most important of the smaller plains are the Arcahaie Plain, the Léogane Plain, and the Cayes Plain. All of these plains, except the Central Plain, have played an important part in the agricultural development of the Republic.

The Cul-de-Sac Plain is one of the most striking geographic features. It is part of a trough extending from Port-au-Prince Bay southeastward across the island to Neiba Bay and containing two lakes that have no outlet, Étang Saumâtre in the Republic of Haiti, and Hoya de Enriquillo in the Dominican Republic. It has been known for a long time that recently, geologically speaking, this trough was below sea level, dividing the island into two parts.

Aside from these plains most of the Republic, except part of the Northwest Peninsula, is mountainous. The highest mountains are in the southern part of the Republic. Mt. La Selle, the highest peak according to available information, has an altitude of 2,680 meters above sea level, as determined by triangulation under the supervision of the United States Geological Survey.

Contrary to the prevailing opinion the major geographic features are arranged in arcs convex both northward and southward. Most of the arcs trend northwestward. The geographic provinces, some of which have not heretofore been named, and their characteristic surface features are described in the final report.

GEOLOGY

Sedimentary rocks.—The oldest sedimentary rocks are schists that crop out on the North Plain and on Tortue Island. As these

rocks are not close to any known intrusive igneous rocks, and as they are so altered by metamorphism, it is believed they may be as old as Paleozoic.

Extensive areas in the northern part of the Republic contain argillites of supposed lower Cretaceous age. These sediments were deposited principally along the flood plains of streams. Impure marine limestones, probably of the same age, were found in the southern part of the Republic. Upper Cretaceous limestones that contain reefs of the peculiar rudistid mollusks found in Jamaica and other West Indian islands were discovered in the Arrondissements of Cap-Haïtien and Grande-Rivière du Nord.

Rocks of Tertiary age are very widely distributed in the Republic. Their succession and their equivalents in the Dominican Republic and other regions near by are shown in the table on page 20. The Eocene and Oligocene rocks are almost exclusively limestones, but the Miocene and Pliocene beds consist principally of clastic rocks. The Eocene and Oligocene limestones crop out on the crest and flanks of the mountains, and the Miocene and Pliocene clastic rocks in the plains and lowlands.

The Eocene is the most extensive series of rocks in the Republic. The Plaisance limestone, of middle Eocene age, is confined to the northern part of the Republic. It is characterized by undescribed species of Foraminifera of the genus *Dictyoconus*.[2] Limestone of upper Eocene age is perhaps the most common surface rock in the mountains and it has a maximum thickness of more than a thousand meters. It contains an extensive foraminiferal fauna, principally orbitoidal Foraminifers of the genera *Orthophragmina* and *Lepidocyclina*. Upper Eocene Foraminifera were collected at about 90 localities.

Rocks of known lower Oligocene age were not seen during the reconnaissance. Middle Oligocene limestones were found in many parts of the Republic, particularly in the Montagnes Noires, the Chaîne des Mateux, and near Jacmel. These rocks are characterized by certain species of *Lepidocyclina*. Limestones of upper Oligocene age are extensive around the borders of the Plaine Centrale, in the mountains north of Étang Saumâtre, south of Gros-Morne, and elsewhere. They contain the foraminiferal genera *Lepidocyclina*, *Niogypsina*, and *Sorites*, and a fairly large coral fauna.

[2] See Woodring, W. P., Middle Eocene Foraminifera of the genus *Dictyoconus* from the Republic of Haiti: Journ. Washington Acad. Sci., **12**: 244-247, 1922.

TERTIARY SEDIMENTARY ROCKS OF THE REPUBLIC OF HAITI

AMERICAN TIME SUBDIVISION		REPUBLIC OF HAITI		DOMINICAN REPUBLIC		LOCALITIES OF SOME OTHER AMERICAN EQUIVALENT	EUROPEAN TIME SUBDIVISIONS
Pliocene.		Hinche formation (non-marine). Conglomerates and marl near Jacmel.		Las Matas formation (non-marine.)		Panama, Jamaica, Cuba, and Costa Rica.	Sicilian. Astian. Plaisancian.
Miocene.	Upper.			Cerros de Sal formation.		Yorktown and Duplin formations of Virginia and North Carolina.	Pontian Sarmatian. Tortonian.
	Middle.	Conglomerate, sandstone, and limestone along south edge of the Plaine du Cul-de-Sac.		Yaque group.	Mao clay. Mao Adentro limestone. Gurabo formation.	La Cruz marl, Cuba; Bowden marl, Jamaica; upper part of Gatun formation, Panama; Porto Rico; Calvert, Choptank, and St. Mary's formation, Maryland and Virginia.	Helvetian.
	Lower.	Artibonite group.	Las Cahobas formation.		Cercado formation.	Middle part of Gatun formation, Panama; Porto Rico; Shoal River marl and Oak Grove sand members of Alum Bluff formation, Florida.	Burdigalian.
			Thomonde formation and Maïssade tongue.		Baitoa formation.*		
			Madame Joie formation.		Bulla conglomerate.*	Lower part of Gatun formation, Panama; eastern Porto Rico; Chipola marl member of Alum Bluff formation, Florida.	
						Anguilla; St. Croix;	

				ber of Alum Bluff formation, Florida.	
Oligocene.	Upper.	Limestone around border of the Plaine Centrale and elsewhere.	Cevicos limestone. Limestone east of Baní and elsewhere.	Anguilla; St. Croix; Porto Rico; Cuba; Panama; Tampa, Florida. Byram calcareous marl,‡ Mississippi.	Aquitanian. Chattian.
	Middle.	Limestone in Montagnes Noires, Chaîne des Matheux, and elsewhere.	Tabera formation.† Limestone near Túbano.	Antigua; St. Croix; Porto Rico; Cuba; Panama; eastern Mexico; Glendon limestone, Gulf States.‡	Rupelian.
	Lower.			Red Bluff clay, Alabama and Mississippi; Marianna limestone, Gulf States.	Lattorfian.
Eocene.	Upper.	Limestone in all the mountain ranges.	Limestone at Damajagua, in Sierra de Neiba, Sierra de Bahoruco and elsewhere.	St. Bartholomew; Cuba; Trinidad; Ocala limestone, and Jackson formation, Gulf States.	Priabonian.
	Middle.	Plaisance limestone.		Claiborne group, Gulf States.	Auversian. Lutetian.
	Lower.			Trinidad; Midway and Wilcox groups, Gulf states.	Ypresian. Sparnacian. Thanetian. Montian.

* Largely contemporaneous.
† May include lower Oligocene.
‡ Age based on unpublished information furnished by C. W. Cooke.

Miocene rocks, consisting principally of conglomerate, sandstone, siltstone and marl, floor the Central Plain, the Artibonite Valley and other lowlands. Crumpled Miocene rocks extend along the southern edge of the Cul-de-Sac Plain and are exposed in road cuts and ravines near Port-au-Prince. A preliminary account of the Miocene beds of the Central Plain has already been published.[3] Copies of this report may be obtained by applying to the Engineer-in-Chief of the Republic of Haiti. The Miocene rocks in the Central Plain were studied in greater detail than those of any other region, and extensive series of fossils were collected. The Thomonde formation, one of the divisions of the Miocene beds, contains a molluscan fauna of more than 300 species, in addition to Foraminifera, corals, and Bryozoa. A limestone at the base of the overlying Las Cahobas formation contains a large number of reef corals. Other collections of Miocene corals and mollusks were obtained at many localities in the Artibonite Valley and elsewhere. A description of unusual specimens of *Orthaulax aguadillensis* Maury, one of the most striking and common mollusks in the Thomonde formation, is awaiting publication.[4]

Marine rocks of Pliocene age were found in the valley of Rivière Gauche and in nearby regions near Jacmel. An interesting fauna of corals and mollusks was obtained from these beds. Flood-plain deposits, called the Hinche formation, cover extensive areas in the Central Plain. These and similar beds in other lowlands may be of Pliocene age.

Marine Pleistocene deposits, consisting principally of coral reef rock and coralliferous limestone, were discovered in many parts of the Republic. They are most extensive in the western part of the Northwest Peninsula, where they cover the Bombardopolis Plateau and the magnificent emerged terraces that lead down from the plateau to the sea like gigantic stairs. In this part of the Republic these Pleistocene rocks are at an altitude of 400 meters above sea level. Pleistocene coral reefs were found in the Cul-de-Sac Plain, especially along the southern border of Étang Saumâtre. Pleistocene flood plain deposits are common in the lowlands.

More than 300 collections of fossils were obtained from the Cretaceous, Tertiary, and Pleistocene rocks, including Foraminifera, corals, crinoid stems, Echini, Bryozoa, brachiopods, mollusks, ostracods,

[3] Woodring, W. P., Stratigraphy, structure, and possible oil resources of the Miocene rocks of the Central Plain: Rep. Haiti Geol. Survey, 19 pp., map, 1922.

[4] Woodring, W. P., Tertiary mollusks of the genus *Orthaulax* from the Republic of Haiti, Porto Rico, and Cuba: Proc. U. S. Nat. Mus. (in press).

barnacles, decapod Crustacea, fish, birds, mammals, and plants. The largest number of collections are from Eocene and Miocene rocks, which are the most widely distributed. Unusually interesting collections of extinct Quaternary mammals and birds were obtained from caves near St.-Michel de l'Atalaye. In addition to remains of ground sloths and rodents, parts of a huge barn owl were found. This owl must have been a very powerful bird and apparently was the marauder responsible for the numerous remains of rodents found in the caves. Accounts of these remains have been published.[5] Further exploration of these and other caves should reveal a large Pleistocene fauna.

A paper describing the fossil plants collected, all of which are of Miocene age, is also in press;[6] another paper describes Miocene fish remains.[7]

Igneous rocks—Most of the igneous rocks are older than the sedimentary rocks and crop out on the crests of anticlinal arches in the mountains or in deep valleys where streams have cut through the cover of sedimentary rocks.

The oldest known igneous rocks are principally basalts that cover large areas in the northern part of the Republic. They are intruded by pyroxenites, peridotites, and diabases. These early igneous rocks are generally much altered and metamorphosed. Pyroxene and hornblende andesites and dacites in the same region are somewhat younger. Eruptions of basaltic rocks followed the andesites in some localities. There are minor amounts of tufaceous and agglomeratic rocks associated with the lava flows. All these volcanic rocks are the result of intense and long continued vulcanism in probably early and middle Mesozoic time.

The widely distributed basalts of the southern part of the Republic are of late Cretaceous age. They are remarkably uniform over the entire Southern Peninsula.

Toward the end of Cretaceous time or in early Eocene time the old lavas and younger argillites in the northern part of the Republic were intruded by batholiths and stocks of quartz diorite. The older igneous

[5] Miller, G. S., Jr., Remains of mammals from caves in the Republic of Haiti: Smithsonian Misc. Coll., 74[3]: 8, 1922.

Wetmore, A., Remains of birds from caves in the Republic of Haiti: Smithsonian Misc. Coll., 74[4]: 4, 2 text figs., 1922.

[6] Berry, E. W., Tertiary fossil plants from the Republic of Haiti: Proc. U. S. Nat. Mus. (in press.).

[7] Cockerell, T. D. A., A fossil Cichlid fish from the Republic of Haiti: Proc. U. S. Nat. Mus. (in press).

rocks are greatly altered near the contacts. Dacite porphyry in the Montagnes Noires may be of the same age.

In the Terre-Neuve district stocks of Quartz diorite were intruded into the old lavas and the Eocene limestone probably during Miocene time. This intrusion has a direct bearing on the genesis of the ore deposits of the Terre-Neuve district.

At the end of middle Oligocene time there were flows of nephelite basalt, an unusual type of rock in the West Indies, in the mountains between the Cul-de-Sac Plain and the Artibonite Valley.

Several hundred specimens of igneous rocks were collected. Chemical analyses have been made of 5 specimens.

Tectonics.—During late Mesozoic and Tertiary time the West Indian region was part of the great equatorial geosyncline that apparently almost completely encircled the globe. In the Republic of Haiti, as in other parts of the geosyncline, the Mesozoic and Tertiary rocks were crumpled during the Alpine period of folding. One of the surprising results of the reconnaissance is the discovery that the tectonic features of so large a part of the Republic are due to folding and crumpling of the rocks during and at the end of Miocene time. The Montagnes Noires, the Chaîne des Mateux, and its prolongation eastward to the Dominican border, are anticlinal arches formed at the end of Miocene time. The Central Plain, Artibonite Valley and Cul-de-Sac Plain are deep synclinal troughs of the same age. Miocene beds are involved in the folding in the Northwest Peninsula. Many of these mountain ranges and troughs are bordered by high-angle thrust faults. A zone of imbricated high-angle thrust faults is well exposed along the southern border of the Cul-de-Sac Plain. Similar thrust faults were found along the northern border of the plain, showing that this trough is not a down-faulted block, bounded by normal faults, as had previously been supposed. Marine Miocene beds underlying an interior lowland in the Commune of Jérémie are now separated from the sea by a high range composed of limestone of upper Eocene age. Lignite-bearing beds of Miocene age at Camp Perrin are thrust northward and are separated from the Cayes Plain by a range of upper Eocene limestone probably thrust northward.

The results of the folding at the end of Miocene time are most apparent in the central part of the Republic, which was very mobile during most of Tertiary time and where a great thickness of Oligocene and Miocene deposits were laid down. The movements continued into Pliocene time, as marine Pliocene beds near Jacmel are crumpled.

It is believed that there were earlier periods of folding at the end of Cretaceous time and at the end of Eocene time, but the folds can hardly be disentangled from the more extensive folds at the end of Miocene time, as they usually have the same trend.

No extensive overthrust sheets such as characterize the Alpine folds in so many parts of the Tertiary equatorial geosyncline were discovered, although there are many high-angle thrust faults along which the horizontal movement has not been very great.

In the mobile central part of the Republic and in the Northwest Peninsula the distribution of the emerged Pleistocene coral reefs is directly related to the folds produced at the end of Miocene time. The coral reefs, or coralliferous limestones, are at the greatest altitude on the crests of the anticlines, clearly showing that the arching of the rocks continued during Pleistocene time. These movements probably are going on even at the present time.

The tectonic features, like the geographic features which they control, are arranged in arcs convex northward and southward. Most of the arcs trend northwestward, but an arc in the Northwest Peninsula bends southwestward and at the western end of the Southern Peninsula arcs branch out in sheaf-like fashion.

Troughs like the Central Plain, Artibonite Valley and Cul-de-Sac Plain, which clearly are deep synclines bounded in part by high-angle thrust faults, are similar to the much larger submerged troughs of the West Indies, like the Bartlett Deep. It has been suggested that the submerged troughs are similar tectonic features.[8] The submerged troughs have heretofore been interpreted as down faulted blocks bounded by normal faults.

Earthquakes.—The Republic, like other parts of the Tertiary equatorial geosyncline, has numerous earthquakes. Disastrous earthquakes have at times almost or completely destroyed Port-au-Prince, Cap-Haïtien, and other cities. Father Scherer, Director of the Observatoire Météorologique du Séminaire-Collège St.-Martial, years ago ably showed the relation between the earthquakes and the known tectonic features. This relation and the bearing of the earthquakes on methods of building construction are discussed in the final report.

[8] See Wooding, W. P., Tectonic features of the Republic of Haiti and their being on the geologic history of the West Indies: Abstract, Journ. Washington Acad. Sci. (in press).

MINERAL RESOURCES

Metals.[9]—At the present time there are no active mining operations in the Republic, although prospecting has been carried on in several regions and some ore has been shipped.

The Terre-Neuve district contains probably the most extensive ore deposits. Copper is the principal metal in the deposits of this district, but there are small amounts of silver and gold. The ore deposits are contact metamorphic deposits in the upper Eocene limestone at the contact with the intrusive quartz diorite, and vein deposits in the porphyritic phase of the quartz diorite, and in the older basalts and pyroxene-andesites. Chalcopyrite is the principal copper mineral in the contact metamorphic deposits. Bornite and chalcocite are the principal copper minerals in the enriched vein deposits. Most of the ore is of low grade, although small amounts of rich ore are found both in the contact metamorphic deposits and in the enriched veins. More thorough prospecting is needed to reveal fully the possibilities of the district.

Copper-bearing veins were examined at a number of other places in areas of pre-Tertiary igneous rocks. Near Grande-Rivière du Nord there are small veins of solid chalcocite ore, but large amounts of low grade ore would have to be mined in order to work them.

Deposits of manganese ore, apparently hot springs deposits, were discovered in the Commune of Gros-Morne. The deposits examined are of low grade and contain a prohibitive amount of silica. Another deposit at the contact between upper Eocene limestone and basalt north of Jacmel is similar in many features to the deposit in the Commune of Gros-Morne.

Deposits of magnetite and hematite were examined at Morne Beckley in the North Plain. In many parts of the Republic there are residual deposits of low grade iron ore consisting of hematite and clay.

Fifteen samples of ores have been assayed and analyzed.

Non-metals.—The Republic of Haiti contains probably the most extensive deposits of lignite in the West Indies. Miocene beds in the Central Plain near Maïssade contain beds of high-grade lignite that have a maximum thickness of 2 meters or more. All of the beds examined contain partings of carbonaceous clay and bone that would

[9] The statements on the metals and non-metals here given were translated into French and published in Rapport annuil de l'Ingénieur en Chef au Secrétaire d'État des Travaux Publics, Répub. d'Haiti, pp. 50–52, 1922.

have to be discarded in mining operations. In a large part of this potential lignite field the beds dip very gently and the lignite could be mined by stripping off the overburden. The Miocene beds in this part of the Central Plain are coastal swamp deposits.

Lignite of entirely different origin and composition was examined in the interior lowland at Camp Perrin in the Arrondissement of Cayes. The beds here, which are also of Miocene age, are non-marine, and the lignite is probably an undeveloped cannel coal. This lignite could hardly be profitably mined, as the beds of good lignite are thin and all the beds are crumpled and faulted. Samples of lignite from both regions have been analyzed.

Miocene beds in the Central Plain contain mother rock and reservoirs suitable for the accumulation of oil. Favorable structural features were examined and have already been described.[10] Seeps of oil from these rocks have been reported by several people, but were not examined during the reconnaissance. There are no large-scale seeps, residues, or mud volcanoes, such as are found in many other regions where rocks of the same age contain oil. The oil possibilities of the Central Plain can be tested only by the drill.

Samples of limestone, marl, and argillite have been analyzed to determine the possibility of using them as raw materials in the manufacture of cement. Samples of different kinds of rock, gravel, and other material have been tested as road material. Gravels and sands have been tested as material for concrete and for other uses. Samples of clay have been tested as material for making bricks. The Republic contains a variety of rocks suitable for building stone and an unlimited supply of limestone that is burned for lime. At several places salt is obtained by the evaporation of sea water. Samples of cave guano have been analyzed to determine their value as fertilizers.

UNDERGROUND WATER RESOURCES

Perhaps the most intimate contact between geology and the inhabitants of the Republic lies in the development of the water resources. Most of the inhabitants depend upon agriculture for their livelihood and in many parts of the Republic it is necessary to supplement rainfall with irrigation. At the time of the reconnaissance there was little information available concerning the surface water resources. A program of measuring the flow of streams that are most

[10] Woodring, W. P., Stratigraphy, structure, and possible oil resources of the Miocene rocks of the Central Plain: Rep. Haiti Geol. Survey, 19 pp., map, 1922.

important with regard to present and proposed irrigation projects is now being carried out. During the reconnaissance a considerable amount of time was spent in studying the underground water resources of certain regions.

As soon as we arrived in Port-au-Prince, Mr. Brown began an examination of the geology of the region near Port-au-Prince with regard to the public supply of water. The present supply is derived from springs and during years of abnormally low rainfall it is inadequate for the rapidly increasing population of the capital. Mr. Brown made suggestions for the more effective utilization of some of the springs that are controlled by the geologic features. The water issuing in the springs falls as rain on the crest and north slope of Morne Hôpital, and as this mountain is composed wholly of limestone the water contains a large amount of calcium bicarbonate. The possibility of treatment to remove the hardness is discussed in the report. Ultimately the city should have a stream-fed supply. The Grande Rivière de Léogane (or Rivière Momance) probably contains an adequate amount, and as basalt is the surface rock in the greater part of its watershed its water should be much softer than the water derived from the springs near the city.

Mr. Brown also examined the inadequate spring-fed supply of Cap-Haïtien. Water of good quality to supplement or replace the present supply could be obtained from wells in the North Plain near by.

In the Cul-de-Sac Plain water derived from flowing and non-flowing wells is used to supplement the surface waters in irrigation. The possibility of obtaining a similar supply in some of the other plains is fully discussed in the report.

In many regions where limestone is the surface rock there are no surface streams, as the water seeps into channels and caverns in the limestone. At many places in limestone regions the inhabitants must depend for their supply upon salty springs issuing at the coast. At some of these places it is possible to obtain better water at little cost by tapping farther from the coast the underground streams feeding these springs.

The Republic contains many types of unusual springs, such as warm springs, sulphur springs, and salty springs. The geologic features of these springs were examined and samples of water from them were analyzed. There are also several interesting lakes, among them Étang Saumâtre. Samples of water from the lakes were analyzed. In all, 20 samples of water from streams, lakes, springs, and wells

were analyzed. The quality of these waters and the source of their mineral content are discussed in the report.

It is thus apparent that the reconnaissance has yielded results that are important contributions to the geologic history of the West Indian region. It has also yielded results that in many ways have an intimate bearing on the welfare of the inhabitants of the Republic—results based on an understanding of the geologic features derived from observations that at first glance may seem to be of purely scientific interest only.

BIOLOGY.—*The origin of the vertebrates.* AUSTIN H. CLARK, National Museum.

Heretofore all the writers on the subject of the evolution of the vertebrates have approached the problem with the complex vertebrate structure admittedly or unconsciously dominating the perspective within which all other types of animal structure should fall. Under the influence of this preconceived though unconfessed idea either a devious line was traced from the vertebrates through progressively simpler forms eventually ending in the protozoans, or a line was drawn from the protozoans to the vertebrates from which more or less numerous side branches were given off terminating blindly in supposedly anomalous types.

It never seems to have been noticed that animals and plants are but slightly different manifestations of the same organic phenomena, and that therefore there is no reason to suppose that the evolutionary line in one kingdom would be in its broader features greatly different from that in the other.

In the following pages I shall attempt to show that if we consider the phanerogam-like radially symmetrical colonial coelenterate type as representing the culmination of animal evolution properly so called, and the bilateral animals as having arisen through the disruption of this type and the gradual geometrical recombination of the characters of the forms resulting from this disintegration, we shall have an explanation of the origin of all the different animal types by which each and every one is allocated and shown to be a necessary element in the general plan.

The embryological processes common to all animals show that the egg develops into a blastula which subsequently becomes a gastrula; but from this point onward the developmental processes exhibit no features common to all animal types.

The gastrula, present in the ontogeny of all animals, is the last structural complex which is of universal occurrence throughout the animal kingdom and the last common bond between the various animal types, and it therefore must in some way represent the starting point for all subsequent divergence.

An egg typically divides into two, four and eight cells in three planes each of which is at right angles to the other two and, equal cell division continuing, a hollow sphere is formed, the blastula, which collapses, forming a more or less hemispherical structure with two layers of cells, an outer and an inner, the gastrula.

The gastrula possesses a single axis which runs through the center of the opening resulting from the collapse of the blastula; but since the walls of the gastrula are everywhere the same there is a perfect radial symmetry about this axis.

Since the gastrula, though usually in a considerably modified form, is common to all animal types and forms the starting point for the divergence of the various major groups, it is important to determine what its real significance is.

From the egg through the blastula to and including the gastrula there is a direct geometrical continuity leading to the formation of a body radially symmetrical about a single axis. The logical termination of such development would be the formation of an animal type in which the gastrula axis persists to the adult and the body of the adult is radially symmetrical about it.

If the facts presented by a study of embryology are significant in indicating the phylogeny of animals, it is clear that the last common ancestor of all the bilaterally symmetrical animal types was a radially symmetrical form, or a sort of adult gastrula.

There are two such animal forms. In one of these, the sponges, the body consists of a community of cells imperfectly integrated and showing relatively little devision of labour or unified life. The sponges continue to grow throughout life, and their increase is always radial.

In the other, the coelenterates, the body is a distinct unit of more or less definite size with a gastrovascular cavity and a well developed muscular system. Growth in the coelenterates as in the sponges is continuous throughout life; but since the complexity of the organization imposed a definite maximum size on the individuals, the growth impetus results in the continued formation of new individuals which bud off from those preceding, typically resulting in an arborescent or mass colony comparable to that seen in the phanerogams. While in many coelenterates the budded individuals become free, and in some

there is no budding at all, there can be no doubt that fundamentally the coelenterates are phanerogam-like colonial animals.

There is nothing that can be assumed to connect the sponges with any other animal type except, perhaps, with certain of the Protozoa. It is evident that the gastrula stage in the development of the bilateral animals cannot represent any sponge-like progenitor. It is possible, however, to interpret the bilateral animals in terms of the colonial coelenterate. Indeed, it is not possible to interpret them in any other way, for any other explanation of their origin would assume the presence of a fundamental bilateral tendency, an unknown and undeterminable variable not common to all animal types.

If a colonial coelenterate with radially symmetrical polyps should develop a persistent defect in the ontogeny whereby the units became bilaterally symmetrical, bilateral animals of four main types would at once appear:

1. Bilateral animals in the form of a linear more or less unified colony.

2. Bilateral animals in which the colony formation was inverted, the budding of the new elements taking place within the original unit.

3. Bilateral solitary animals each representing a dissociated coelenterate unit; and

4. Bilateral animals with the colonial habit, though independent of each other.

These four main types, between which there would be numerous intergrades, all represent definite types occurring among the coelenterates themselves, and therefore none of them can be said actually to represent anything new in animal structure other than the novelty consequent on the developmental defect which resulted in the loss of the radial and the assumption of the bilateral body form.

Among the animals of today all four of these main types are represented:

1. The tape-worms or segmented cestodes form a linear colony of continuous growth so like a partially unified strobila as to leave little doubt of the fundamental similarity of type. The scolex of the cestodes is radially symmetrical, but the proglottides are strongly flattened and bilaterally symmetrical, though the difference between the dorsal and the ventral surface is but little marked.

2. The flukes have a peculiar development which is essentially similar to strobilization, except that the buds are formed within the original unit instead of in a linear series.

In those coelenterates with division of labour the polyps are of three sorts, (*a*) nutritive, or sac-like, (*b*) reproductive, and (*c*) excretory, or "defensive." If in strobilization of the fluke type buds of each of these sorts were formed internally, this would furnish the elements necessary for the creation of the so-called coelome, which is divided into three parts, (*a*) the perivisceral, or sac-like, (*b*) the gonadial, and (*c*) the excretory or nephridial.

The flukes and their allies always retain distinct traces of radial symmetry, especially in their digestive system and in the arrangement of their nerves.

3. The turbellarians and nematodes are bilateral solitary animals, the individuals each comparable to a single coelenterate polyp. All of them show distinct traces of radial symmetry in their nervous system, and the turbellarians also in their digestive system.

4. Such turbellarians as *Microstomum* are single animals each comparable to a single coelenterate polyp; but they divide in such a way as to produce chains of similar attached animals each of which is independent of the others and not a part of a more or less unified entity as in the case of the proglottides of the tape worms.

The cestodes, the flukes, the turbellarians and *Microstomum* are all flat worms and all more or less closely related to each other. They all retain to a very considerable degree traces of radial symmetry and of other coelenterate features. Being intermediate between radially symmetrical and bilaterally symmetrical types it requires very little imagination to assume that they represent the four original types into which the coelenterates disintegrated upon the appearance of that developmental defect which resulted in bilateral symmetry.

If the preceding suppositions are logical it is evident that the so-called evolution of the bilateral animals cannot be evolution in the sense of the progressive development of higher types from lower, but instead must have been a recombination and reassortment of the four diverse features characteristic of the four types into which the radially symmetrical colonial coelenterate type disintegrated. In other words the so-called evolution of animals is in reality a convergence toward a common centre from four equidistant points, and the progressive economic efficiency does not indicate any real phylogenetic progress, but results merely from a more and more intimate intermingling of, and a progressively better balance between, the main features indicated by the tape worms, flukes, turbellarians and *Microstomum* standing at the four corners of the original square.

The four corners of this square are marked by four animal types which are closely related to each other, yet at the same time are fundamentally distinct. One of them indicates the commencement of the segmented body; another shows the beginnings of the coelomic structures; a third is simple, with no indications of segmentation or of a coelome; while the fourth is a colonial form of the third.

From these four points there would proceed evolution of two kinds. Each type would give rise to all economically possible variants through a process of continuous development which could be approximately represented by a branching tree-like figure; but all of the the different forms arising in this fashion would fall strictly within limits of its proper type.

As examples of such evolution may be mentioned the insects, crustaceans, molluscs, annelids, etc., within which groups all the included types may be more or less successfully represented as branches of a tree-like figure at the base of which lies a generalized or primitive form; but this and all the others however much they may diverge in details of structure always agree in their fundamental features.

Since they all have arisen from the same colonial coelenterate-like ancestor which has, so to speak, exploded into four different types, each of these four points represents an animal complex in a state of unstable equilibrium; for each one has latent within it the fundamental features of the other three.

Such an unstable equilibrium, in effect an explosive force, would presumably result in a sudden readjustment of the somatic balance whereby intermediate types would appear, one between each two of the four corners (fig. 1); while these intermediate types, each a distinct re-creation and not genetically connected with either of its neighbors, would show a distinct economic advance, this economic advance would in no way represent real evolutionary progress, for it would be merely the result of the combination of the advantages inherent in the structure of the types on either side.

Thus there would suddenly appear, quite without apparent ancestry, (1) segmented animals, like the tape-worms, with a coelome, like the flukes; (2) unsegmented animals, like the turbellarians, with a coelome like the flukes; (3) solitary unsegmented animals without a coelome, like the turbellarians, but with abundant asexual reproduction, like *Microstomum:* and (4) segmented animals without a coelome, like the tape-worms, but less unified and without the continuous loss of the units, as in *Microstomum.*

All four of these intermediate types actually occur. All are entirely and widely distinct from each other, and show no demonstrable intergradation with any of the remaining animal types, each occupying a markedly isolated position. Three of the four are extraordinarily rich in genera and species; the last and least successful is represented by two closely parallel and non-intergrading forms which are identical with regard to the features with which we are concerned, but differ in all others. One of the first three is the only major animal group which has not persisted to the present time.

The segmented animals with a coelome are the annelids; the unsegmented animals with a coelome are the priapulids and sipunculids;

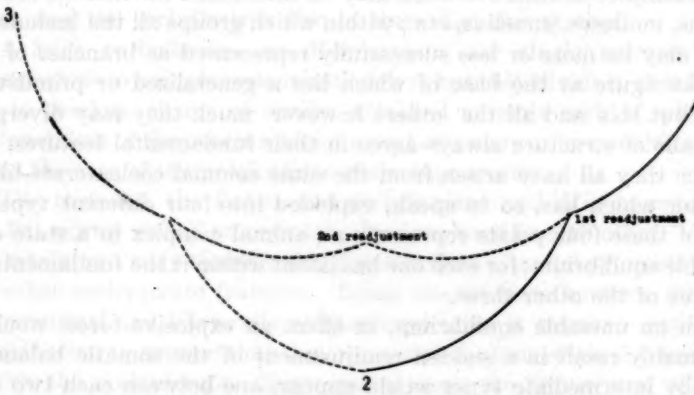

Fig. 1. Showing the first and second readjustments.

the solitary acoelomate animals with abundant asexual reproduction are the rotifers; and the acoelomate animals forming colonies of separate individuals are undoubtedly the graptolites (fig. 3).

Through this readjustment as just described each of the new animal types would combine the features of two of the original types. But since in each of these new types two of the four chief features are absent, there would still exist a condition of unstable equilibrium as compared with the colonial coelenterate-like ancestor.

A second readjustment of the same nature as the first would be inevitable by which four animal types would appear in line with the first, but combining the characters of the intermediates in the second series (fig. 1).

Three such intermediates (fig. 3) seem to be clearly indicated in the polyzoans, colonial and not at all or very imperfectly coelomate, between the rotifers and the graptolites; the arthropods, with a segmented body like that of the annelids, but divided into two or three units showing division of labour (in the insects one controlling and directing, one locomotor, and one performing the digestive, reproduc-

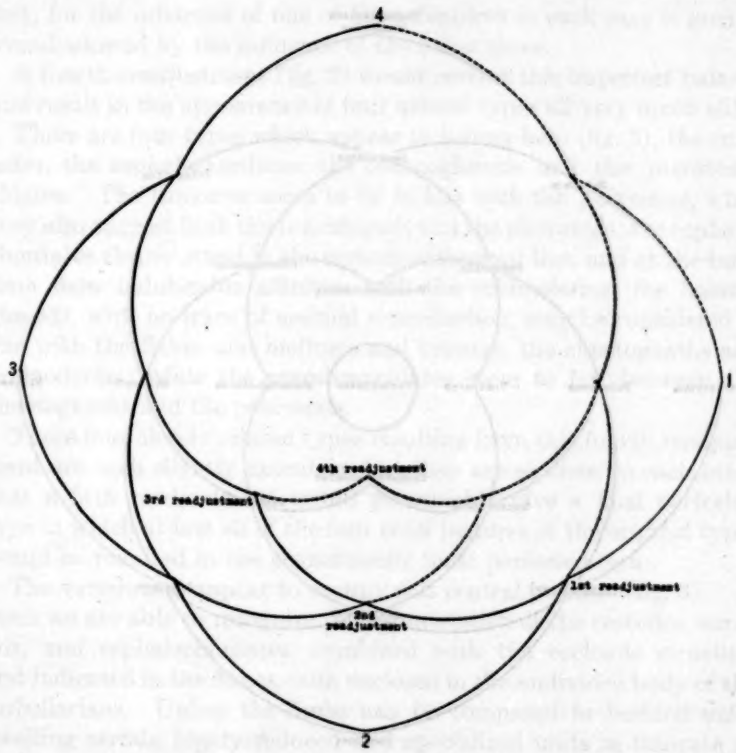

Fig. 2. Showing the first to the fourth readjustments.

tive and other vital functions) after the graptolite or polyzoan fashion, with a poorly developed coelome, with abundant traces of asexual reproduction (polyembryony, parthenogenesis, fragmentation of larvae, etc.), with a marked tendency to form (as in the ants) polyzoan-like colonies with division of labour among the (dissociated) units, and sometimes even forming dendritic colonies (as in *Thompsonia*); and the molluscs, always solitary, like the priapulids and sipun-

culids, with a highly developed coelome, and with traces of segmentation suggesting the annelids. The fourth group should be solitary with an indication of colonial structure and a coelome, but without segmentation. It is possible to place the nemerteans here by assuming their imperfect segmentation to be of the *Microstomum* and not of the tape-worm type.

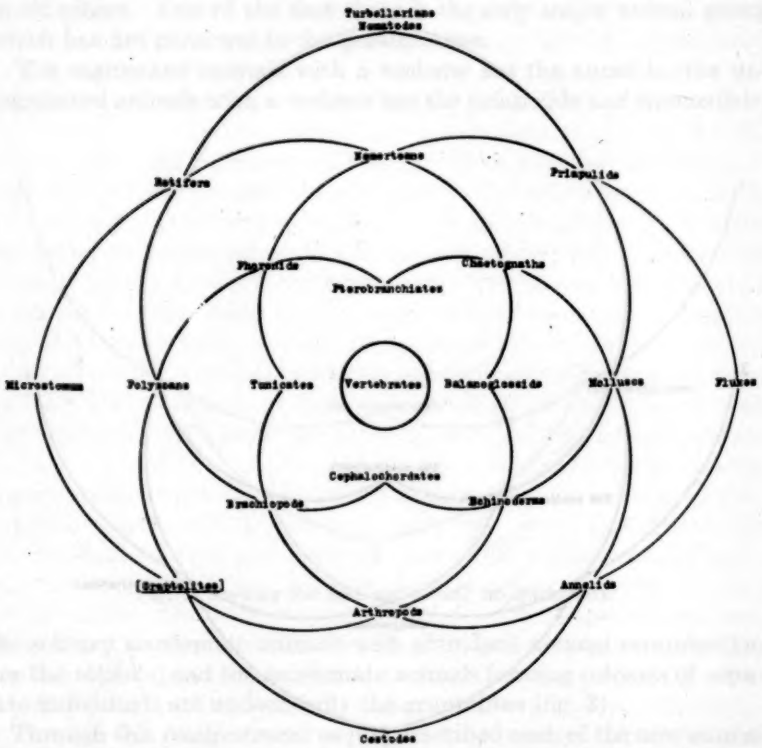

Fig. 3. Showing the development of the various animal types above the coelenterates.

There is still a condition of unstable equilibrium, for in each of these four groups one of the original elements is lacking. A third readjustment (fig. 2) would be necessary to recombine all the main features characteristic of the original four types.

Four animal groups (fig. 3) appear to be the result of such a readjustment. The echinoderms combine a reduced body consisting of five half segments of the arthropod type with a highly perfected coe-

lome; the chaetognaths suggest a relationship with the molluscs, and also with the nemerteans; the phoronids suggest a relationship with the polyzoans, but have a well developed coelome, and the colonial habit is reduced to the budding off of new individuals; and the brachiopods suggest both the polyzoans and the barnacle-like arthropods.

While by this third readjustment all the four original features are recombined in each animal type, the balance between them is imperfect, for the influence of one of these features in each case is greatly overshadowed by the influence of the other three.

A fourth readjustment (fig. 2) would correct this imperfect balance and result in the appearance of four animal types all very much alike.

There are four types which appear to belong here (fig. 3), the tunicates, the cephalochordates, the balanoglossids and the pterobranchiates. The tunicates seem to be in line with the polyzoans, while they also suggest both the brachiopods and the phoronids; the cephalochordates clearly stand in the cestode-arthropod line, and at the same time show indubitable affinities with the echinoderms; the balanoglossids, with no trace of asexual reproduction, may be considered in line with the flukes and molluscs and between the chaetognaths and echinoderms; while the pterobranchiates seem to fall between the chaetognaths and the phoronids.

These four closely related types resulting from this fourth readjustment are each slightly excentric; but they are so close to each other that a fifth readjustment would presumably give a final perfected type in which at last all of the four chief features of the original types would be reunited in the economically most perfected form.

The vertebrates appear to occupy this central position (fig. 3). In them we are able to recognize the segmentation of the cestodes, annelids, and cephalochordates, combined with the coelomic structure first indicated in the flukes, both enclosed in the undivided body of the turbellarians. Unless the limbs can be compared to budded units recalling certain highly reduced and specialized units in tunicate or polyzoan colonies, the influence of the feature represented by *Microstomum* seems to have disappeared.

In the course of the various readjustments which culminated in the formation of the vertebrates numerous secondary features, such as visual and other sense organs, appendages of different kinds, diverticula and other outgrowths from the enteric canal, chitinous and calcareous skeletons, etc., all of which exist in the coelenterates and in one or other of the four types derived immediately from them, became enormously developed and specialized in correlation with the

increasing bodily efficiency resulting from the recombinations. But if the analysis of the origin of the various animal types just given is an approximately true exposition of the facts, the vertebrates, in spite of their wonderful complexity of structure and their very high degree of efficiency, represent nothing more than the final recombination of characters already occurring in the colonial coelenterates which were widely dissociated at the inception of bilateral symmetry.

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

PHILOSOPHICAL SOCIETY

877TH MEETING

The 877th meeting was held in the Cosmos Club Auditorium on Saturday, January 27, 1923. The meeting was called to order at 8:15 P.M. by President WHITE with 29 persons in attendance.

Mr. G. T. RUDE presented a paper on *Instruments and methods for the observation of tides*. The paper was illustrated with lantern slides, and was discussed by Messrs. LAMBERT, BOWIE, PAULING, HUMPHREYS, HAWKSWORTH, FARIS, LITTLEHALES, and TUCKERMAN.

Author's abstract: A continuous record of the rise and fall of the tide is necessary in connection with a number of engineering and scientific problems.

The simplest method of tidal observation consists in observing the changing height of the water as noted on a fixed vertical staff. From this it was but a step to devising some mechanical means for recording automatically the rising and falling of the surface of the sea.

The earliest automatic tide gauge of which we have record was devised by an English civil engineer, Henry R. Palmer, and is described in the Philosophical Transactions of the Royal Society, London, for the year 1831.

Of the automatic tide gauges, two classes may be recognized: (1) those in which the changes in elevation are shown in the form of a curve; (2) those in which the height of the water at definite intervals is shown by means of figures, or the so-called printing gauges. The various forms of the tide gauges in use were shown by means of slides and attention called to the distinguishing features.

Special attention was directed to a new type of automatic tide gauge recently developed in the office of the Coast and Geodetic Survey for use of hydrographic parties in the field. In designing this instrument the objects sought were ease of installation and minimum size commensurate with the desired accuracy. The gauge is about 10 inches long and 9 inches high. The clock is placed inside the cylinder carrying the cross-section paper on which the curve of the tide is drawn. No counterpoise weight is used, a coiled spring taking the place of the weight. The float well is ordinary 3½ inch stock iron pipe and in addition to serving as a float, it acts as a support for the gauge. No platform is necessary for the installation of this gauge, which may be lashed to a pile on a bar or to net stakes in bays or rivers. A metallic cover furnishes the only shelter necessary.

Messrs. G. W. VINAL and G. N. SCHRAMM presented a paper on *The tarnishing and detarnishing of silver*. The paper, which was illustrated by lantern slides, was presented by Dr. VINAL and discussed by Messrs. PAULING, HAWKSWORTH, HUMPHREYS, LAMBERT, GISH, HEYL, and SHOWEY.

Author's abstract: The tarnish observed on silver is ordinarily the sulphide. It was found that hydrogen sulphide causes tarnishing of silver when moisture is present, and particularly when sulphur dioxide is also present.

The electrolytic method for detarnishing silver is based upon the fact that the silver immersed in a solution of salt and soda and in contact with and electro-positive metal forms a cell in which the hydrogen passing to the silver reduces the sulphide, liberating hydrogen sulphide. The reduced silver is left upon the surface in the moss condition.

The tarnishes formed a definite color scale which may be used to estimate the extent of the tarnish. The colors are as follows: Yellow, red, purple, blue, blue-green, gunmetal, black.

Experiments were made to study the tarnishing of silver in solutions and gas atmospheres, and conditions for establishing a standard tarnish were determined. The thickness of the tarnish film was found to range from 0.18 to 0.36 microns, which is about 2 per cent of the thickness of the silver plating. Sterling silver tarnishes more readily than pure silver. Tarnishing is accelerated by the presence of moisture, sulphur dioxide and certain films on the surface of the silver, such as alkali and soap films. The tarnishing of silver may be retarded by the action of several reagents.

Comparisons between various electrolytic devices for detarnishing were made. There is practically no loss of silver by the electrolytic method of cleaning, unless the moss silver is present in objectionable amounts. Silver losses are appreciable when the cleaning is done by abrasives and cyanide solutions. The potential differences between the silver and the various metals used for the cleaner were determined.

Adjournment at 10:01 P.M. was followed by a social hour.

J. P. AULT, *Recording Secretary.*

SCIENTIFIC NOTES AND NEWS

At the Physics Club, Bureau of Standards, on February 26, Dr. W. F. MEGGERS spoke on *Line structure in complicated spectra.*

The subject was introduced by a general outline of the earlier known regularities in the spectra of the chemical elements beginning with the Balmer series of hydrogen and followed by the types of series found in the relatively simple spectra characteristic of the elements in the first three columns of the periodic classification. There are four general types of series, principal, sharp, diffuse, and fundamental, each of which may be represented by single, double, or triple spectral lines. Doublets, triplets, and more complex structures are explained as arising in a multiplicity of P, D, and F energy levels between which electron transitions take place. The S term is generally single. In addition, certain inter-combinations of these series may represent observed spectral lines.

The quantum theory assigns azimuthal quantum numbers 1, 2, 3, and 4 respectively to the four general types of series and restricts inter-combinations to those involving a change of only one unit in quantum number. The sum of azimuthal and radial quantum numbers determines the position (term number) of a line in a series. An "inner quantum number" is asso-

ciated with the multiple levels representing each P, D, or F term and composite doublets and triplets containing so-called satellites are explained by changes of plus one, minus one, or zero in the inner quantum number. The same theory attempts to account for a new type of regularity shown by groups of lines called "multiplets" which have recently been found in the complicated spectra of manganese, chromium, and molybdenum. In the arc spectrum of manganese, for example, groups of 9, 13, or 15 lines are apparently explained by changes in inner quantum numbers assigned to 3P, 5D, and 7F levels when the 9, 13, and 15 line multiplets represent intercombinations of PD, DD′, and DF terms respectively. In its present state, however, the theory is unable to predict the exact character or location of regularities in unclassified spectra.

The Pick and Hammer Club met on Saturday evening, February 24, in the Director's room of the Geological Survey. The *Foreign situation of petroleum* was discussed by E. DE GOLYER, and the *Domestic situation of petroleum*, by G. B. RICHARDSON.

A party of observers from the U. S. Coast and Geodetic Survey is at work in southern California to determine the distance between Mount Wilson and San Antonio Peak. The distance between these two peaks is about 20 miles, and a base approximately parallel to the line joining them and having a length of approximately 20 miles has been located in the valley or plains just to the south of the two peaks. The work involved in this project consists of observations for triangulation and trionometric leveling, the measurement of the base line with an accuracy not less than one part in a million, the determination of the deflection of the vertical in both the meridian and the prime vertical, and some precise leveling. Each section of the base will be measured at least four times with different tapes in order to secure this high degree of accuracy.

The Division of Physical Anthropology, U. S. National Museum, has received casts of the two recently discovered ancient Obercassel skulls with parts of the skeletons. The Museum has now very nearly a complete set of casts of early human remains, and with one or two exceptions they are all first-hand casts made directly from the originals, which enhances their value.

Miss FLORENCE BASCOM, Professor of Geology at Bryn Mawr College, is spending the winter months in Washington completing her work for the U. S. Geological Survey.

Mr. S. R. CAPPS has returned from private geologic work abroad to duty as geologist in the U. S. Geological Survey.

Mr. E. T. HANCOCK, formerly geologist on the U. S. Geological Survey, now employed by the Standard Oil Company in Roumania, visited Washington in the latter part of February.

Mr. F. E. MATTHES of the U. S. Geological Survey gave an illustrated address on March 5 before the New York Academy of Sciences on the subject of *The evolution of the Yosemite Valley*. He also spent a day at the American Museum of Natural History inspecting the new large relief model of

the Yosemite Valley that is being prepared under the direction of Dr. E. O. HOVEY.

Dr. CHARLES MOON of Cornell University, began work at the Bureau of Standards on February 6, in the Section of Induction and Capacity, Electrical Division.

Dr. EDWARD W. MORLEY, emeritus professor of chemistry at Western Reserve University, and one of the most famous American scientists, died on February 26 at Hartford, Connecticut, in his 86th year. He was born at Newark, New Jersey, January 29, 1838. He was educated at Williams College and received honorary degrees from that university and also from Western Reserve, Lafayette, Pittsburgh, Wooster, and Yale, also holding the professorship at Cleveland Medical College from 1873–88. Among notable prizes awarded to Professor Morley were the Davy Medal of the Royal Society in 1907, Cresson Medal of the Franklin Institute in 1912, and the Gibbs Medal in 1916. His work on the atomic weight of oxygen and the densities of oxygen and hydrogen is known to all chemists, while the Michelson-Morley experiment is one of the most fundamental in physics. Professor Morley was a member of the ACADEMY and of many national and foreign chemical and physical societies.

Dr. F. C. WEBER, for many years chemist in the Bureau of Chemistry, U. S. Department of Agriculture, has resigned to accept a position with the Fleischmann Company, New York, N. Y.